Improving Power Transmission System Stability in Nigerian using Statcom Device Controller

Ilo, Frederick Udebunu, Anumaka, Michael Chukwukadibia., Akwukwargbu, Isdore Onyema

Abstract: *The instability of power transmission system in Nigeria is the concern of many individual and that is what this paper wants to address. The first stage was to analyze the effect of static synchronous compensator (STATCOM) on power transmission stability. In doing that, the three phase fault was introduced to the system at line 4-5. The Load flow simulation analysis was carried out according to IEEE 9 bus system. The power transmission system model was developed and simulated using MATLAB/SIMULINK software. The result of the simulation shows that Bus 5 was detected to violate the voltage limit of 0.95 < V< 1.05 p.u. having a voltage magnitude of 0.8875p.u. The per unit Voltage magnitude of power system with STATCOM and without STATCOM was calculated. From the result, the voltage magnitude without STATCOM was 0.8875p.u while that with STATCOM was 1.01p.u. The total active power Loss without STATCOM was 324.02MW while that with STATCOM was 322.53MW. Therefore the percentage of power system improvement is 0.23% when STATCOM was incorporated. Finally, Power transmission system improves when STATCOM was applied.*

Keyword: *Power system stability, STATCOM, MATLAB/SIMULINK, Transmission*

I. INTRODUCTION

Power system is a complex network which comprises of generators, transmission lines, variety of loads and transformers. When the demand of power is increasing, there will be more loads on transmission lines. The challenges facing transient stability after the occurrence of real fault can result to as limiting transmission factor as long transmission lines loaded increased (Mihalic, Zunko & Poul, 1996). The stability of Transient system enables the maintainability of synchronous performance in many disturbances; examples are switching of lines or multi-phase short-circuits faults (Padiyar, 2002). Therefore the system Stability always acts on both the starting operating and exactness condition of the disturbance. Present technology of power electronics employs the application of flexible AC transmission system (FACTS) controllers in power transmission system. Hence, the FACTS controllers are applied to control the states of the system network in a high speed and at the same time improve the voltage stability, steady state and complex Transient power system stability (Igor &Zunko, 2002; Prechanonkumkratug, 2009). In electrical power system, the major advantages of reactive power compensation was to increase system stability, voltage regulation, enhancement of machine performance, power loss reduction, voltage collapse control and voltage sag. The transmission line impedances are one of the factors affecting lagging VAR machines in a generating system which can cause the system instability in transmission lines (Truong, 2012). So, unusual voltage drop can also cause increase in power losses which may result to power outages in transmission lines. Thus, the reactive power compensation cannot only extenuate all the system effects but help the system to respond to transient faults and disturbances. Most importantly, the transmission lines should ease of the effect of reactive power on generators or loads. The shunt compensator that was planted very close to load, in a distribution or transmission substation can mitigate the effect of reactive power Salem & Altawil, 2014).Therefore the major benefit of FACTS was to restore the system network fast with inductive or capacitive reactive power while improving the power transmission systems quality and efficiency. Finally, the STATCOM controller was a voltage-source inverter (VSI), which normally converts a DC input voltage in to AC output voltage with active and reactive power system compensation Pokharel &Wenzhong, 2010; Han, Huang, Baran, Bhattacharya, Litzenberger, Anderson, Johnson &Edris, 2008; Wei, Venayago moorthy& Harley, 2009).

II. STATCOM CONTROL MECHANISM

The STATCOM controller is a solid state switching control system capable of performing or absorbing real and reactive power output independently. When the input terminal was connected to energy source or storage system, then the equivalent model of STATCOM controller was connected to power system. The STATCOM was modeled in a shunt compensation component which produces either leading or lagging current into AC system. It was fundamentally designed for improvement of voltage in power system when reactive power was short circuited. The system was made to be conciseonprecedence electronics voltage-source converters which were capable of tracking down indiscreet AC controlling electricity network.

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There will be an increase in conferral fund, if the AC power preponderance joins with the control system. Generally, STATCOM is introduced in order to indorse electricity system networks of voltage regulation. Thus, STATCOM provides voltage source converter (VSC) device with the backward voltage reactor. The DC capacitor of voltage drop generated and STATCOM tremendously gives full sate capacities. The terminal of reactive power of STATCOM reliance on the voltage source amplitude (Arabi, Hamid &Fardanesh, 2002). So, STATCOM electrical device provides high speed reactive power compensation with high voltage transmission and improvement of voltage and power system stability, a PSS is also designed with STATCOM in order to filter voltage instability. The application of thyristor is also designed with STATCOM with PSS controller (Gounder, Nanjundappan &Boominathan, 2016;Wang, Haochang, Kuan& Prokhorov, 2017).

III. STATCOM WORKING PRINCIPLE:

The principle of STATCOM device is normally based on reactive-power source. This generates the actual reactive power absorption and generation through the process of electronics source of the voltage and current waveforms. The figure1 shows the principle of STATCOM with Voltage source converter(VSC) and a reactance. Therefore the shunt reactors and capacitors banks are not necessary for reactive power generation and absorption; thus provides stocky design of STATCOM. Therefore the coupling transformers have two modes. The first role is to connect the converter to the high voltage power system. Secondly, to ensures the transformer inductance of DC capacitor is not short-circuited and discharged rapidly (Rong, Wanpeng, Jian&Yapeng, 2013; Saad, Lisboa, Kanayake, Jenkins &Strbac (2011).

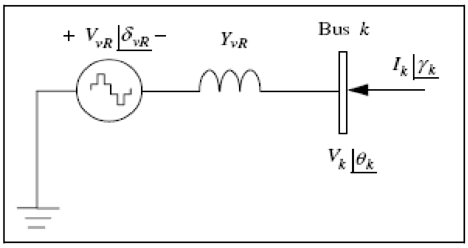

Figure1: Diagram of STATCOM working Principle

V_1 is the terminal bus voltage, V_2 is the output voltage of STATCOM, V_{dc} is the DC capacitors, X_L is the inductive reactance, and δ is the phase angle of V_1 with respect to V_2.

General mathematical equation of STATCOM for active or real power, reactive power and STATCOM output voltage can be expressed as follows:

$$P = \frac{(V_1 V_2)Sin\delta}{X_L} \qquad (1)$$

The relationship between fundamental component of the converter AC output voltage and voltage across DC Capacitor is given as:

$$Q = \frac{V_1(V_1 - V_2 Cos\delta)}{X_L} \qquad (2)$$

Where K is coefficient which depends upon on the converter configuration, number of switching pulses and the converter controls

$$V_{out} = KV_{dc} \qquad (3)$$

The following operation modes of STATCOM are given:

(a)- ***Normal excited mode of operation*** **(V_2=V_1):** If the output voltage is equal to the AC system voltage, then there active power exchange is zero.

(b)- *Over exited mode of operation* ($V_2 \geq V_1$):

If the amplitude of the output voltage is increased above that of the AC system voltage, then the current flows through the reactance from the STATCOM to the AC system and the STATCOM generates reactive (capacitive) power for the AC system.

(c)-*Under exited mode of operation* ($V_2 \leq V_1$):

If the amplitude of the output voltage is decreased below that of the AC system, then the reactive current flows from the AC system to STATCOM, and the STATCOM absorbs the reactive (inductive) power for the AC system.

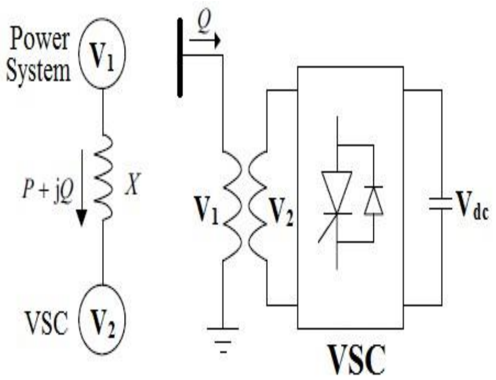

Fig. 2: shunt solid state voltage source (Acha, Fuerte- Esquivel, Hugo & Cesar, 2004).

The shunt voltage source of the three-phase STATCOM may be represented by:

$$E_{VR}^{\lambda} = V_{VR}^{\lambda}\left(\cos\delta_{VR}^{\lambda} + j\sin\delta_{VR}^{\lambda}\right) \qquad (4)$$

Where δ indicates phase quantities a, b and c. The voltage magnitude V_{VR}, produces maximum and minimum limits which depends on the function of STATCOM capacitor rating. Also δ_{VR} is between 0 and 2π radian.

$$[I_k] = [Y_{VR} \ -Y_{VR}]\begin{bmatrix} V_K \\ E_{VR} \end{bmatrix} \qquad (5)$$

$$I_K = \left[I_k^a \angle \gamma_k^a \quad I_k^b \angle \gamma_k^b \quad I_k^c \angle \gamma_k^c\right]^t \qquad (6)$$

$$V_K = \left[V_k^a \angle \theta_k^a \quad V_k^b \angle \theta_k^b \quad V_k^c \angle \theta_k^c\right]^t \qquad (7)$$

$$E_{VR} = \left[V_{VRK}^a \angle \delta_{VRK}^a \quad V_{VRK}^b \angle \delta_{VRK}^b \quad V_{VRK}^c \angle \delta_{VRK}^c\right]^t \qquad (8)$$

$$Y_{VR} = \begin{bmatrix} Y_{VRK}^a & 0 & 0 \\ 0 & Y_{VRK}^b & 0 \\ 0 & 0 & Y_{VRK}^c \end{bmatrix}$$

IV. MATERIAL AND METHOD

The bus at which the STATCOM was connected was represented as a PVS bus, which may change to PQ bus in the event of limits being violated. In such a case, the generated or absorbed reactive power would correspond to the violated limit. Unlike the SVC, the STATCOM was represented as a voltage source for the full range of operation, enabling a more robust voltage support mechanism.

(a) Power Flow Equations

To enhance optimal power flow, STATCOM was incorporated into the power flow network. The device was attached to a suitable bus m, and the expression of the source voltage is given by:

$$E_{rs} = V_{rs}(\cos\delta_{rs} + j\sin\delta_{rs}) \qquad (9)$$

Where E_{rs} is the source voltage from STATCOM,
$V_{rs}$is the terminal voltage of STATCOM
δ_{rs} *is the phase angle*
The complex power of STATCOM is a function of the terminal voltage and the conjugate of the current flowing through it. Equation (10) and (11) express the conjugate current and the complex power respectively.

$$I_{rs}^* = Y_{rs}^*(V_{rs}^* - V_m^*) \qquad (10)$$

$$S_{rs} = V_{rs} I_{rs}^* \qquad (11)$$

By expanding and solving the complex equation, the equations for active and reactive power for STATCOM and its bus of attachment was derived. The power components of the converter are given by equations (12) and (13), while the power components at bus m, where it was attached is given by equations (14) and (15)

$$P_{rs} = V_{rs}^2 G + V_{rs}V_m[G\,\mathrm{Cos}(\delta_{rs} - \phi_m) + B\,\mathrm{Sin}(\delta_{rs} - \phi_m)] \qquad (12)$$

$$Q_{rs} = -V_{rs}^2 B + V_{rs}V_m[G\,\mathrm{Sin}(\delta_{rs} - \phi_m) - B\,\mathrm{Cos}(\delta_{rs} - \phi m \qquad (13)$$

$$P_m = V_m^2 G + V_m V_{rs}[G\,\mathrm{Cos}(\phi_m - \delta_{rs}) + B\,\mathrm{Sin}(\phi_m - \delta_{rs})] \qquad (14)$$

$$Q_m = -V_m^2 B + V_m V_{rs}[G\,\mathrm{Sin}(\phi_m - \delta_{rs}) - B\,\mathrm{Cos}(\phi_m - \delta rs \qquad (15)$$

From the power equations derived, the linearized model of STATCOM was represented by a Jacobian matrix which is given by equation (16).

$$\begin{bmatrix} \Delta P_m \\ \Delta Q_m \\ \Delta P_{rs} \\ \Delta Q_{rs} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_m}{\partial \phi_m} & \frac{\partial P_m}{\partial V_m}V_m & \frac{\partial P_m}{\partial \delta_{rs}} & \frac{\partial P_m}{\partial V_{rs}}V_{rs} \\ \frac{\partial Q_m}{\partial \phi_m} & \frac{\partial Q_m}{\partial V_m}V_m & \frac{\partial Q_m}{\partial \delta_{rs}} & \frac{\partial Q_m}{\partial V_{rs}}V_{rs} \\ \frac{\partial P_{rs}}{\partial \phi_m} & \frac{\partial P_{rs}}{\partial V_m}V_m & \frac{\partial P_{rs}}{\partial \delta_{rs}} & \frac{\partial P_{rs}}{\partial V_{rs}}V_{rs} \\ \frac{\partial Q_{rs}}{\partial \phi_m} & \frac{\partial Q_{rs}}{\partial V_m}V_m & \frac{\partial Q_{rs}}{\partial \delta_{rs}} & \frac{\partial Q_{rs}}{\partial V_{rs}}V_{rs} \end{bmatrix} \begin{bmatrix} \Delta \phi_m \\ \frac{\Delta V_m}{V_m} \\ \Delta \delta_{rs} \\ \frac{\Delta V_{rs}}{V_{rs}} \end{bmatrix} \qquad 16)$$

The STATCOM voltage magnitude V_{rs} and (phase angle $\partial\delta_{rs}$ are used as the state variables with correction values $\Delta V_{rs}$and $\Delta\delta_{rs}$ respectively which are added for each iteration. The derivatives of active power P and reactive power Q form the Jacobian matrix's element. The initial estimates of the state variables are introduced at the beginning of iterations. The new voltage profile at bus m was given by equations (17) and (18)

$$V_{rs}^{(i)} = V_{rs}^{(i-1)} + \Delta V_{rs}^{(i)} \qquad (17)$$

$$\delta_{rs}^{(i)} = \delta_{rs}^{(i-1)} + \Delta\delta_{rs}^{(i)} \qquad (18)$$

Where 'i' is the number of iteration

V. SIMULATION RESULTS AND DISCUSSION

The simulation results are presented to improve Power transmission system without and with STATCOM device and also comparing the power loss of power system without STATCOM and with STATCOM.

Three phase fault was introduced to the system at on line 4-5. Load flow simulation was carried out on a faulty IEEE 9 bus system. Figure 3 and Table 1 shows the result of the simulation. Bus 5 was detected to violate the voltage limit of 0.95 < V< 1.05 p.u. having a voltage magnitude of 0.8875p.u. This indicates that there was power system instability

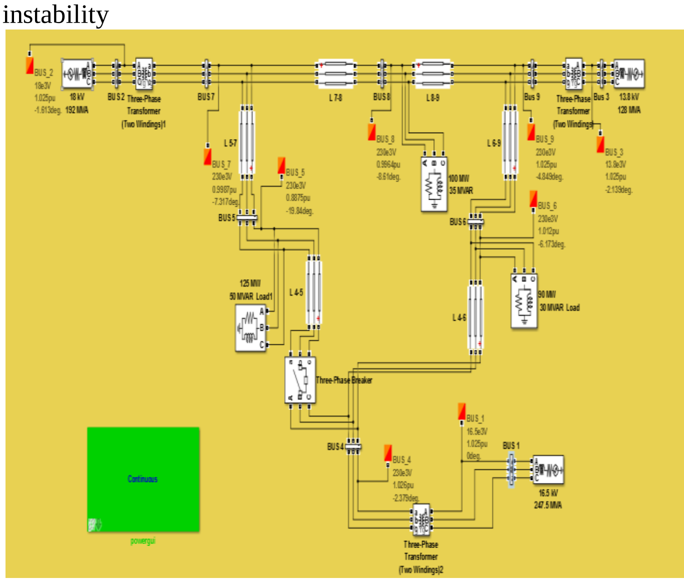

Figure 3 Simulink model of load flow on a faulty 9-Bus IEEE system

Table 1: Table showing the load flow result of a faulty 9 bus IEEE system without STATCOM

BUS	Voltage (p.u.)	Voltage Angle (deg)	PGEN (MW)	QGEN (MVAR)	PLOAD (MW)	QLOAD (MVAR)
BUS_1	1.025	0	76.02	-0.62	0	0
BUS_2	1.025	-1.61	163	51.45	0	0
BUS_3	1.025	-2.14	85	2.1	0	0
BUS_4	1.0264	-2.38	0	0	0	0
BUS_5	0.8875	-19.84	0	0	125	50
BUS_6	1.0122	-6.17	0	0	90	30
BUS_7	0.9987	-7.32	0	0	0	0
BUS_8	0.9964	-8.61	0	0	100	35
BUS_9	1.0251	-4.85	0	0	0	0
			324.02	52.93	315	115

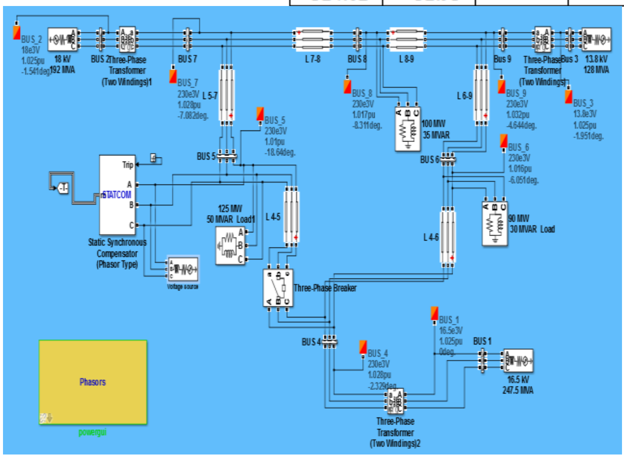

Figure 4: Simulink model of load flow result on a faulty 9-Bus IEEE system with incorporation of STATCOM

From table 2, the insertion of STATCOM into the network, there was a considerable improvement in the voltage profile of the system. The voltage at bus 5 was regulated from 0.8875 p.u. to 1.01 p.u. other buses that experienced voltage improvement are buses 4, 6, 7, 8 and 9 with increase from 1.0264 p.u., 1.0122 p.u., 0.9987 p.u., and 0.9964 p.u. to 1.0276 p.u, 1.0156 p.u., 1.028 p.u., 1.017 p.u., and 1.032 p.u. respectively. It can also be seen that STATCOM injected more reactive power into the system in order to obtain improved voltage profile and stability at the buses.

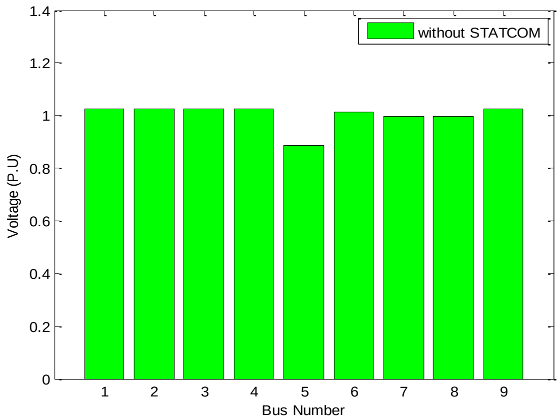

Figure 5: Per-Unit Voltage stability of power system without STATCOM

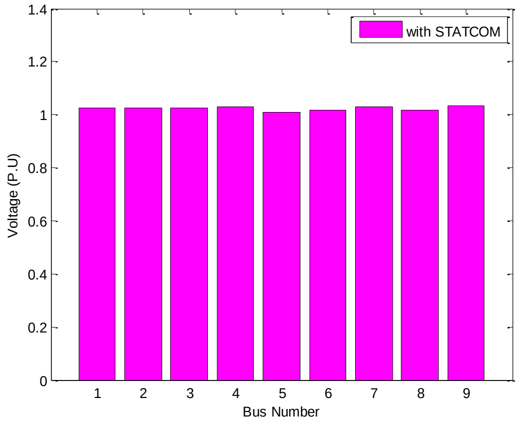

Figure 6: Per-Unit Voltage stability of power system with STATCOM

Table 2: Load flow solution of 9-Bus IEEE system with SATCOM

BUS	Voltage (p.u.)	Voltage Angle (deg)	PGEN (MW)	QGEN (MVAR)	PLOAD (MW)	QLOAD (MVAR)
BUS_1	1.025	0	74.53	-2.95	0	0
BUS_2	1.025	-1.54	163	3.22	0	0
BUS_3	1.025	-1.95	85	-10.03	0	0
BUS_4	1.0276	-2.33	0	0	0	0
BUS_5	1.01	-18.64	0	0	125	92.73
BUS_6	1.0156	-6.05	0	0	90	30
BUS_7	1.028	-7.08	0	0	0	0
BUS_8	1.017	-8.31	0	0	100	35
BUS_9	1.032	-4.64	0	0	0	0
			322.53	-9.76	315	157.73

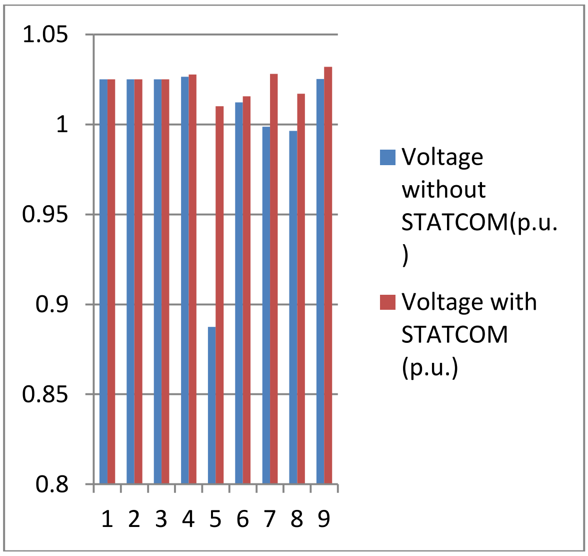

Figure 7 Graph showing the voltage profile at the buses without STATCOM and with STATCOM.

The graph in figure 7 shows the voltage magnitude of the power system without and with STATCOM. Bus 5 was seen to have a voltage boost which allows it to fall within the voltage limit range.

VI. CONCLUSION

This paper has discussed the important of STATCOM on power transmission system stability. The STATCOM was applied to enhance optimal power flow into the power flow network. The device was attached to a suitable bus m, and the expression of the source voltage was generated. The Three phase fault was was detected to violate the voltage limit of 0.95 < V< 1. introduced to the system at on line 4-5. Load flow simulation was carried out on a faulty IEEE 9 bus system. MATLAB/SIMULINK software was performed to carry out analysis on power transmission system. The result shows that Bus 5 05 p.u. having a voltage magnitude of 0.8875p.u. Hence voltage magnitude without and with STATCOM are 0.8875p.u and 1.01p.u respectively. The total active powers Loss without and with STATCOM are 324.02MW and 322.53MW. Therefore the percentage of power system improvement was 0.23% when STATCOM was incorporated. Finally, Power transmission system improves when STATCOM was applied.

REFERENCES

1. Pokharel, B. &Wenzhong, G. (2010).“Mitigationofdisturbancesin DFIG basedwindfarmconnectedtoweakdistribution system using STATCOM”,NorthAmericanPower Symposium,1-7.
2. Han, C., Huang, A., Baran, M., Bhattacharya, S., Litzenberger, W., Anderson, L., Johnson, A. &Edris, A. (2008).STATCOMimpactstudyontheintegrationofalarge windfarmintoaweaklooppowersystem,*IEEETrans on EnergyConversion*,23(1), pp. 226-233.
3. Acha, E., Fuerte-Esquivel, C.R., Hugo A.&CesarA. (2013). “*ModellingandSimulationinPowerNetworks:* John Wiley & Sons, Ltd.
4. Rong, F., Wanpeng, S., Jian, Y. &Yapeng, J. (2013). Studyon applicationofSTATCOMin voltagestabilityofwind farmincorporatedsystem,*Chinesecontrolconference*, 2013.
5. Igor, P. &Zunko, P. (2002).Mathematical model and steady state operational characteristics of a unified power flow controller, *Electro technical Review*, 69(5), pp285-290.
6. Wang, L., Chang, C., Kuan, B. &Prokhorov, A. V. (2017). “Stability ImprovementofaTwo-AreaPowerSystem ConnectedWithanIntegratedOnshore andOffshore Wind Far UsingaSTATCOM. IEEEtransactionsonindustryapplications, vol. 53(2), March/April2017
7. Prechanonkumkratug (2009).Application of UPFC to increase transient stability assessment of a power system,*Journal of computer*, 4(4) pp283-287.
8. Wei, Q., Venayagamoorthy, G. &Harley, B. (2009).“Real-time implementationofa STATCOM on a windfarmequipped withdoubly fedinduction generatorsindustry application: *IEEE Transactions*45(1), PP. 98-107.
9. Salem, Q., &Altawil, I. (2014).Stability study of grid connected to multiple speed wind farms with and without FACTS integration. **International Journal of Electronics and Electrical Engineering** 2(3), 2014
10. Mihalic, R., Zunko, P. &Poul, D.(1996).Improvement of Transient stability using unified power flow controller” *IEEE Transaction on power delivery*. 11(1) pp.485-491
11. Padiyar, R.(2002). *Power system dynamic stability and control*, second edition.
12. Saeed, A., HamidH., &Fardanesh, B. (2012). “Convertible StaticCompensatorPerformance Studies on theNY State TransmissionSystem” *IEEE transactions on power systems*,vol. 17(3), August, 2002
13. Truong, T.K. (2012). Improvement of LVRT characteristic of SCIG wind turbine system by incorporating PMSG. International Journal of Energy, information and communication 3(3).
14. Gounder, Y.K.., Nanjundappan, D. Boominathan, V. (2016). Enhancementotransientstability ofdistribution systemwithSCIGandDFIG basedwindfarmsusing STATCOM.IET*Renewable Power Generation*,16th June2016
15. Saad, Z., Lisboa, M., Kanayake, J., Jenkins, N. &Strbac, G. (2011)."Application of STATCOMs towindfarms. *IEEE proceedingsonGeneration, Transmission and Distribution*; 145(5).